BRINE INJECTION OF RED MEAT

by

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INTRODUCTION

Consumer buying- and lifestyles have changed over the years. This required the meat industry to look for new, improved technologies in order to live up to the modern consumers' needs. These technological improvements allow consumers to prepare meat products quickly and easily, while improving overall product quality and consistency (Baumert & Mandigo, 2005). One such a process employed by the meat industry, in an attempt to satisfy these changing needs, is brine-injection. It is also described as enhancing or value-adding. The United States Department of Agriculture-Food Safety and Inspection Service (USDA- FSIS) (2011a), describes enhanced meats as meats containing flavouring solutions, added by means of marinating, needle-injecting and soaking, etc. A new rule, to exclude the term 'enhanced' from the label of products with added solutions, was proposed by the USDA-FSIS in July 2011. They recognised that the term 'enhanced' might mislead the consumer to judge the 'enhanced' product as inferior in value, compared to unenhanced products.

Injection technology in the meat industry started back in the 1950's in the poultry industry (Buchanan, 1955). The pork industry saw this new injection technology as an opportunity and took advantage of it, thereby providing consumers with enhanced pork. There is very little injection technology involved in red meat at the moment (Sheard, Nute, Richardson, Perry & Taylor, 1999; Vote, Platter, Tatum, Schmidt, Belk, Smith & Speer, 2000; Department of Agriculture, Fisheries & Forestry (DAFF), 2002; Xiong, 2005; Feiner, 2006). According to Corrigan (2011), the USDA reported that approximately 30% of poultry, 90% of pork and 15% of beef are enhanced with solutions. Value-adding in beef was with chuck and round by the research and development team of The National Cattlemen's Beef Association (NCBA) experimented with chuck and round. They discovered that value-adding could also be employed in the beef industry. This association was founded in the United States (US) in 1997. They found that the best approach to add value to the carcass, is to merchandise it as individual muscles, rather than as groups of muscles or muscle pieces (Patterson, 2006). The growth of value-added beef cuts, at retail and food service levels in the US, started to accelerate in 2006 (Wald, 2006). In lamb, there has been a positive innovation in terms of 'soft' value-adding through the introduction of innovative cuts, such as racks of lamb and boned-out legs (DAFF, 2002).

Meat is pumped or injected with a variety of compounds designed to enhance its sensory properties, for instance: texture, flavour, colour, juiciness and consistency. Research in the field of enhanced meats (Vote *et al*., 2000; Robbins, Jensen, Ryan, Homco-Ryan, McKeith & Brewer, 2002; Morgan, 2003; Baublits, Pohlman, Brown & Johnson, 2005; Baumert & Mandigo, 2005; Xiong, 2005; Feiner, 2006; Hoffman, 2006; Hamling & Calkins, 2008; Hoffman, Muller & Vermaak, 2008; Parsons, VanOverbeke, Goad & Mireles-DeWitt, 2011a) has shown that ingredients typically used in enhancement solutions include: salt, sodium-based phosphates, hydrocolloids, starch, antioxidants, seasonings as well as flavourings.

FUNCTIONALITY OF INGREDIENTS

The functionality of the non-meat ingredients varies. It depends on the application and contribution to the flavour as well as the appearance. The most common functions discussed in trade publications and research papers are:

- Water holding capacity that:
  - Contributes to improved juiciness and tenderness of the finished product
  - Increases yields of processors
  - Reduces cooking losses
- Serves as flavour enhancers
- Extends shelf-life by reducing microbial growth and delaying rancidity
- Improves colour stability

Water

Water, as the main non-meat ingredient, is very important. According to Baczwaski & Mandigo (2003), water quality must be taken into consideration. Hard water delays the solubility of phosphates, salts, certain non-meat ingredients and other ingredients with high molecular weights. Contaminants, such as iron and copper in water, increase the probability of lipid oxidation in meat. Water is used as a carrier molecule for non-meat ingredients, because most of the ingredients are water-soluble. Water addition assists in maintaining a moist and juicy product. Water also increases the yield, which is important to the producer, because of the economic advantage (Romans, Costello, Carlson, Greaser & Jones, 2001; Brooks, 2007).

Phosphates

Alkaline phosphates are most commonly used in injection solutions. Sodium tri-polyphosphate (STP) is the predominant phosphate in phosphate blends that are used in the meat industry (Miller, 2010). They improve water-holding capacity (WHC) by increasing the muscle pH (Feiner, 2006). Research (Robbins *et al.,* 2002; Baublits *et al*., 2005; Baumert & Mandigo, 2005) showed the relationship between the level of phosphate and pH. In these studies, pH increased linearly with the amount of phosphate added. Increased pH causes water retention, because greater electrostatic repulsive forces create larger gaps between actin and myosin and allow more water to be bound to the meat proteins (Feiner, 2006). This improves the WHC of the meat. The weight of the sellable product consequently increases. Studies reported increased yields, due to retained water (Boles & Swan, 1997; Boles & Shand, 2001). As the WHC improves, absorbed moisture contributes towards juicy and tender meat products. This phenomenon has also been observed in various studies (Boles & Swan, 1997; Boles & Shand, 2001; Robbins *et al.*, 2002; Kuber & Zerby, 2005; Hoffman, 2006). Phosphates work in synergy with other added ingredients. Their synergistic effect also improves juiciness and tenderness (Sheard & Tali, 2004). Phosphates also delay the process of rancidity by chelating heavy-metal ions which act as pro-oxidants (Feiner, 2006).

Contrary to increasing WHC and improving the meat product, pH may have a negative or detrimental effect on the appearance of meat. An increase in pH adversely affects the colour of the meat. Meat becomes darker in colour when the pH increases as a result of the addition of STP. This is due to an increase in the bound water, leaving less free water to reflect light (Miller, 2010). Lawrence, Dikeman, Hunt, Kastner & Johnson (2004) reported that, even though phosphates increase water-binding capacity (WBC) and pumped yields, the muscle-darkening effects would likely decrease consumer acceptance at the retail display case. They observed that beef *longissimus*, enhanced with a phosphate solution, compared to other enhancement solutions, had reduced colour stability and increased off-flavours. Alkaline phosphates can slow down the curing reaction as well. It results in a paler finished product, when used at too high concentrations, especially in rapidly processed meat products (Lynn, 2004).

Salt

Salt is the main ingredient of any enhancement solution (Baczwaski & Mandigo, 2003). Sodium chloride (NaCl), potassium chloride (KCl), lactate and lactate-acetate blends as well as citrates are used in meat and meat products (Feiner, 2006). Several authors (Wismer-Pedersen, 1987; Baczwaski & Mandigo, 2003; Feiner, 2006) have documented that salt fulfils several functions in meat and meat products. In solution, salt has a major effect on the ionic strength. Sodium chloride hydrolyses into sodium ($Na^{+)}$ and chloride (Cl^-) ions. The Na^+ and Cl^- ions bind to the ions on the side chains of the protein, causing electrostatic repulsion. This causes increased WBC in the meat, because there will be a slight movement of the proteins from its iso-electric point to a lower pH. This will depend on the amount of salt added. Purge loss is reduced and cooking yield is improved as a result.

Salt is very important for the functionality of phosphates. In conjunction with phosphates, salt solubilises protein, which, in turn, can immobilise large amounts of added water. This supports the swelling of the protein, as salt acts synergistically with phosphate (Feiner, 2006). Solubilisation of beef myofibrillar proteins therefore, occurs (Baczwaski & Mandigo, 2003).

Traditionally, NaCl has been used as a preservative in curing marinades (Varnam & Surtherland, 1995). It retards microbial activity by lowering the water activity of meat (Stadelman, Olson, Shemwell & Pasch, 1988; Feiner, 2006). Salt levels used in enhancement solutions may have limited antimicrobial effects (Feiner, 2006). Sodium chloride may have adverse effects on meat, such as reducing shelf-life, by acting as a pro-oxidant (Feiner 2006), and causing a rubbery texture when excessive solubilisation of proteins has occurred (Baczwaski & Mandigo, 2003).

Salt is a flavour enhancer when used at lower levels (Brooks, 2007). Sodium chloride is typically used, but where excess sodium content may cause problems, potassium salt may be used (Baczwaski & Mandigo, 2003). Potassium chloride has the disadvantage of having a bitter taste, which can be detected in the end product. Potassium chloride has to be added in higher concentrations than NaCl in order to end up with the same concentration of chloride within the meat product. Excess KCl however, causes heart irregularities in people with heart problems (Feiner, 2006).

When considering the sodium level of meat, it has be taken into consideration that sodium has been added to meat in various forms such as sodium nitrate, sodium erythorbate and sodium phosphates (Feiner, 2006). Sodium chloride and sodium phosphates must be balanced in order to maximize WHC. It should however, not lead to an altered texture or have a very strong salty flavour.

Several studies (Boles & Swan, 1997; Baumert & Mandigo, 2005; Mancin, 2005; Knock, Seyfert, Hunt, Dikeman, Mancini, Unruh, Higgins & Monderen, 2006; Wicklund, Paulson, Rojas & Brewer, 2007; Hoffman *et al*., 2008) found that salts of lactic acids (lactates/lactate-(di)acetate) performed basic functions in brine-injected beef.
These functions include:

- Enhanced safety
- Extended shelf-life
- Stabilised colour
- Improved flavour and tenderness
- Improved cooking yield
- Reduced purge loss.

Lactates are currently introduced into meat products as sodium or potassium. They both work in the same way by extending shelf-life (Feiner, 2006).

Lactates and lactate-(di)acetate blends are used to extend the shelf-life, since they can also function as antimicrobial agents. Lactates inhibit growth of micro-organisms such as *Listeria monocytogenes*, *Clostridium botulinium*, *Esherichia coli (E. coli) O157:H7*, *Salmonella* spp., *Staphylococcus aureus*, *Pseuodomonas* spp., *Campylobacter* spp. and *Yersinia* spp. Lactates bind water, which lowers the water activity (A_w) in the meat product. Growth of micro-organisms is slowed down as a result, because there is less free water for micro-organisms to survive on (Baczwaski & Mandigo, 2003; Feiner, 2006). If certain micro-organisms are targeted, (e.g. *Listeria monocytogenes)* blends (lactate and di-acetate) may be used (Feiner, 2006). They become more effective than when lactate alone is used (Feiner, 2006; Wicklund *et al*., 2007). Lactates have been shown to extend the shelf-life of fresh meat and sausages by 30–50%, cooked and cured products by 30–40%, and cooked uncured products by 50-90% (Feiner, 2006). Addition of lactate to beef products protects against refrigeration irregularities (Baczwaski & Mandigo, 2003).

The shortcoming of sodium acetate and lactates is unwanted flavours in the end product (Baczwaski & Mandigo, 2003). Sodium lactate has the disadvantage of increasing the salty taste of the meat product, as it already contains sodium from NaCl. The problem can be minimized by reducing the amount of NaCl by 2% per kg of the meat product or by using potassium lactate. Unlike sodium lactate, potassium lactate does not contribute to the salty taste (Feiner, 2006). Potassium lactate has a potassium ion substituted for the sodium ion in sodium lactate. Potassium lactate can replace sodium lactate as a non-meat ingredient and functions in the same way as sodium lactate and does not have off-flavour problems like sodium lactate (Miller, 2010).

The other commonly used salt in brine-injected beef is calcium chloride ($CaCl_2$). It has been documented that it improved tenderness and reduced the variation in shear force measurements (Wheeler, Koohmaraie, Lansdell, Siragusa & Miller, 1993, Lawrence *et al*., 2004). Calcium chloride improves tenderness by activating the calpain proteolytic system (Whipple & Koohmaraie, 1992). Research has reported on the detrimental effects on flavour (Wheeler *et al*., 1993; Scanga, Delmore, Ames, Belk, Tatum & Smith 2000). The negative effect of $CaCl_2$ on meat colour is likely due to its oxidative action as a salt, in other words, functioning like a pro-oxidant. Scanga *et al*. (2000) reported metallic and bitter flavours in a calcium marinade solution. When beef flavouring was incorporated into the marinade solution, they found that it reduced the off-flavours. Lawrence *et al*. (2004) overcame the problems in colour and of flavour by using calcium lactate instead of $CaCl_2$. They reported that enhancement with calcium lactate resulted in less colour deterioration because of less metmyoglobin discoloration. Higher L*, a*, and b* values, higher beef flavour intensity scores and lower off-flavour scores were observed when compared to phosphate and salt solutions. Lactate, nevertheless, is known to improve colour stability.

Despite the extensive research done on $CaCl_2$ in enhancement solutions, it is not yet adopted by the meat industry (Brooks, 2007). The limited use of this salt by commercial processors is due to its negative effects on colour and flavour (Lawrence *et al*., 2004).

Natural Tenderisers and Flavourings

Natural tenderisers, that can be incorporated into enhancement solutions to improve the tenderness of beef include: ficin, bromelin and papain. They all originate from tropical plants namely: fig, pineapple and papaya, respectively. They contain both colleagenase and elastase (Romans, 2001; Brooks, 2007; Smith, Tatum, Belk & Scanga, 2008). Papain, in solution, is administered to live cattle. As a result, beef from treated animals will be tenderised (Smith *et al*., 2008). They degrade the muscle protein, but are hard to distribute uniformly throughout beef (Baczwaski & Mandigo, 2003). The right amount of these enzymes should be provided for even distribution to tenderise the meat tissue. Unless temperature and time are controlled, these enzymes contribute towards mushy and strange flavours. These enzymes are therefore not widely used in the US meat industry to improve tenderness (Smith *et al*., 2008).

Natural flavourings, such as rosemary spice, are often incorporated into beef as an enhancement. They are added because of their antioxidant properties, rather than for their flavouring attributes. Morgan (2003) investigated the shelf-life of fresh beef cuts (i.e. strip loin, top sirloin, and shoulder steaks) injected with a solution containing rosemary oleoresin, NaCl and STP. They observed significantly lower thiobarbituric acid reactive substance (TBARS) values on the last day of retail display for all storage periods (1–18 days) in beef cuts injected with rosemary oleoresin. These anitoxidants increase shelf-life by protecting beef against oxidation, causing lean beef to change from red to brown in colour during retail display (Brooks, 2007). Lawrence *et al*. (2004) found that addition of natural flavouring with rosemary extracts, compared to other treatments, enhanced colour stability throughout the retail display period. Rosemary contains the phenolic compounds carnosinic and rosmarinic acids, which decrease the oxidation of oxymyoglobin to metmyoglobin thereby extending colour-life (Lawrence *et al*., 2004).

Organic acids

Organic acids used in meat include: citric, lactic, acetic, benzoic, sorbic and propionic acids (Miller, 2010). They have been used successfully in brine solutions to tenderise meat products (Berge, Ertbjerg, Larsen, Astruc, Vignon & Møller, 2001; Burke & Monahan, 2003). The mean Warner-Bratzler shear force (WBS) value decreased from 178 to 44 N cm^{-2} after marinating with acetic, citric and lactic acid (Burke & Monahan, 2003). Berge *et al*. (2001) injected 0.5 M lactic acid into a collagen-rich beef muscle (*M. pectoralis profundus*).

They observed a marked reduction in toughness and an increased tenderness score as soon as 2 days post-mortem. Mechanisation of the tenderising action by acidic brines is attributed to weakening of the muscle structure, increased proteolysis by cathepsins and solubilisation of collagen (Berge *et al*., 2001; Burke & Monahan, 2003).

Studies performed on beef have shown that the addition of organic acids reduce the pH of the meat. Very low pH impacts negatively on colour as well as the flavour of the meat product. Berge *et al*. (2001) reported a rapid pH drop from 5.5 to around 5.0 within 4 hours of injection with lactic acid. Burke & Monahan (2003) also observed a pH reduction from 5.7 to 3.1, when using acetic, citric and lactic acid. Too high concentrations of organic acids may have detrimental effects on colour stability (Miller, 2010). The meat turns dark grey or grey-brown (Sawyer, Apple & Johnson, 2008). Burke & Monahan (2003) noted that concentrations of organic acids, greater than 0.3M, caused severe swelling, darkening and gelatinization of beef. Sawyer *et al*. (2008) injected 0.75% up to 2% lactic acid in the same way and found a negative impact on fresh beef colour. Panellists described the colour as grey or black and implied that it was perceived as having a well done, cooked appearance. This was, in fact, a premature-browning effect. Subsequent studies (Sawyer, Apple, Johnson, Baublits & Yancy, 2009; Apple, Sawyer, Meullenet, Yancey & Wharton, 2011) concluded that enhancing dark-cutting beef strip loins with lower levels (0.25%) of lactic acid can effectively lower post-mortem muscle pH. This will lead to an improved fresh and cooked beef colour. Post-rigor enhancement of whole dark-cutting beef with lactic acid can eliminate the persistent red/pink cooked colour and off-flavours usually associated with cooked dark-cutting beef.

Hydrocolloids

Non-meat ingredients, namely polysaccharides, are added to pork as bulking and water-binding ingredients. Polysaccharides include: carageenan, konjac flour, xanthan and gellan gums (Baczwaski & Mandigo, 2003, Feiner, 2006). Gums are primarily used in beef products that are low-fat or fat free (Baczwaski & Mandigo, 2003). Xantham gum delays sedimentation of other materials, such as starch, in injection brines for hams, thereby keeping all materials well dispersed for a prolonged period of time (Feiner, 2006). Cold swelling gums or thickeners, such as guar and xantham gums as well as modified starches, achieve high levels of extension in the finished product. This goes against adding real value to meat.

It rather contributes towards high levels of extension of the product. Several countries do not permit the application of such additives as a result (Feiner, 2006).

USAGE LEVELS OF INGREDIENTS

The level of each ingredient in the solution is often expressed as the percentage of the ingredient in the meat product, after injection. Alkaline phosphate levels typically vary between 0.25 and 0.45% of the final product's weight (Feiner, 2006; Brooks, 2007). The pH of the phosphate introduced, should be around 8.7–9.2. A pH above 9.4 increases the pH significantly, thus supporting microbial growth (Feiner, 2006). The legal usage limit of phosphate in enhancement solutions is restricted to 5%. In the finished product, phosphate should not result in more than 0.5%. Since meat already contains 0.01% natural phosphate (phosphorous), this amount should be subtracted when calculating the level of phosphate to be added during curing (Townsend & Olson, 1987).

Depending on country-specific regulations, there is legislation governing the level of ingredients in meat products. The USDA-FSIS (2011b) approved the usage of phosphate at up to 5% in pickle at a 10% pump level. It should however, not exceed 0.5% in the finished meat products. It is specified that only a clear solution may be injected. This is also the case in most countries, such as in Europe and Australia, where phosphate is permitted for usage in meat products. In South Africa, the DAFF is currently reviewing the methods of tenderization under Regulation 4(9), regarding control over the sale of poultry meat (No R.946 of 27 March 1992 as amended by Government notice No. R988 of 25 July 1997). The concentration of phosphate solution, on a mass-per-mass basis, shall not be more than 0.5%. Such a treatment with a chemical solution, may only be carried out on a carcass containing less than 4% absorbed moisture.

The salt content in meat products are not regulated. It is self-limiting because high concentrations thereof will negatively affect the palatability of the product. In brine, salt is generally used at a level of 2%. It can vary from 1.5% up to 3%, depending on the products (Alvarado & McKee, 2007). Salt is formulated to deliver 0.2%–0.4% in the finished meat product (Brooks, 2007). Lactate usage is between 2.8% and 3.5%, calculated per kg of the finished product (Feiner, 2006). Recommended levels of sodium and potassium are 2.5% and 3.0%, respectively (Brooks, 2007). The blends of lactate and di-acetate contain approximately 60% of lactate and 4%, 6%. or 8% of di-acetate. The usage rate of blends containing 4% di-acetate is 25–30g per kg of finished product (Feiner, 2006). Sodium di-acetate is usually added at low levels, not greater than 0.2%, in meat products and is more commonly added at levels of 0.1% to 0.15% in the final product (Miller, 2010). Levels of natural flavourings, like rosemary extract, are generally between 0.05% and 0.2%. These levels vary with the product and the injection level (Brooks, 2007).

EFFECTS OF ENHANCEMENT SOLUTIONS ON SENSORY ATTRIBUTES:

FLAVOUR, TENDERNESS, JUICINESS AND COLOUR

Research (Vote *et al*., 2000; Robbins *et al*., 2002; Morgan, 2003; Baublits *et al*., 2005; Baumert & Mandigo, 2005; Hoffman, 2006; Hamling & Calkins, 2008; Hoffman *et al*., 2008; Parsons *et al*., 2011a) have shown that brine-injection or enhancement improves the sensory quality of beef. Enhancement solutions contain flavour enhancers, such as salts (sodium or potassium lactate/di-acetate) and beef stock or beef broth. Even though salt is seen as a flavour enhancer, it is also a known pro-oxidant. A more improved beef flavour has been reported in brine-injected beef in several studies (Kuber, & Zerby, 2005; Hoffman, 2006; Vote *et al*. 2006; Parsons *et al*., 2011a).

Flavour improvement depends on the ingredients used. Hoffman *et al*. (2008) found no significant differences in aroma and flavour of beef muscles infused with a phosphate and lactate. Lennon, Moon, Ward, O'Neill & Kenny (2006) similarly reported that, the addition of beef stock did not result in higher flavour ratings by sensory panels, compared to the controls. Lawrence *et al*. (2004) reported that beef flavour intensity of *longissimus* steaks was higher in steaks enhanced with a salt-phosphate solution. This was found only when compared to enhancement solutions where beef broth and natural flavourings were incorporated.

Studies found that brine-injection contributes towards a more salty flavour in injected meat (Robbins *et al*., 2002; Hoffman, 2006; Hoffman *et al*., 2008). This could was to be predicted, because of the incorporation of sodium salts (NaCl, sodium lactate, STP, etc). Apart from that, the meat product already contains Na^+ from NaCl. An extremely salty taste can, nevertheless, be reduced by reducing the amount of NaCl by 2% per kg of the meat product. Another option is to use potassium lactate instead of sodium lactate. Unlike sodium lactate, potassium lactate does not contribute to a salty taste (Feiner, 2006). Parsons *et al*. (2011a) compared two different brine-injections (4.5% sodium-based phosphate and 1% ammonium hydroxide) and observed a more salty taste in beef loins, injected with a sodium-based phosphate brine had a saltier taste than loins injected with ammonium hydroxide (NH_4OH).

Off-flavours such as soapy, metallic, sour and bitter have been reported in brine-injected beef. These off-flavours are caused by different ingredients also used in the brine. Phosphate has been shown to cause off-flavours when it is used alone in brine solutions (Vote *et al*., 2000; Robbins *et al*., 2002). Off-flavours were also reported when $CaCl_2$ (Wheeler *et al*., 1993; Scanga *et al*., 2000) and sodium acetate (Baczwaski & Mandigo, 2003) were incorporated into brine solutions.

Tenderness is generally measured by a combination of subjective texture panels and objective shear force resistance measurements. Sensory panellists found that brine-injection improves tenderness and juiciness of red meat (Robbins *et al*., 2002; Baublits *et al*., 2005, Kuber & Zerby, 2005; Hoffman, 2006; Hamling & Calkins, 2008; Hoffman *et al*., 2008; Parsons *et al*., 2011a). Most of these studies reported lower WBS resistance values in brine-injected beef than in non-injected beef (Vote *et al*., 2000; Kuber & Zerby 2005; Hoffman, 2006; Lennon *et al*., 2006).

Lower shear force values are associated with more tender meat, while higher shear force values are associated with tough meat. Baublits *et al*. (2005) observed no significant differences in WBS force values between treated and untreated beef steaks. Sensory panelists rated treated steaks more tender than untreated steaks. Parsons *et al*. (2011a) injected beef loins with 4.5% sodium-based phosphate and 1% NH_4OH brine solutions. They reported no significant differences in tenderness from both WBS and trained panellists. Injection of beef loins with a solution containing only STP was not effective in improving tenderness (Vote *et* *al*., 2000). The abovementioned findings unequivocally prove that brine ingredients are crucial in producing ameliorated meat, which is totally acceptable to the consumer.

It is known that high temperature, above 65ºC, toughens meat, more especially cuts with low amounts of connective tissue (Romans *et al*., 2001). In the case of brine-injected meat, high temperature actually did not have any detrimental effect. Vote *et al*. (2000) reported more pronounced beneficial effects on shear force values and juiciness in brine-injected beef steaks when compared to the control steaks, cooked to internal temperature of 77ºC. The same phenomenon was also observed in pork by Baublits, Meullenet, Sawyer, Mehaffey & Saha (2006) and Brashear, Brewer, Meisinger & McKeith (2002). Baublits *et al*. (2006) observed that untreated pork chops, cooked to 82°C, were less juicy than untreated chops, cooked to 71°C. Enhanced chops however, retained palatability at high temperatures. Brashear *et al*. (2002) observed that moisture-enhanced pork chops, cooked at 70ºC, were found to be more tender when it was compared with non-enhanced pork chops. They observed no differences in shear force values between enhanced and non-enhanced pork when pork chops from both treatments were cooked to an 80°C endpoint. The abovementioned findings indicate that temperature endpoint has to be a crucial consideration when the effects of brine-injected products' tenderness and juiciness are evaluated.

One of the determinants of meat quality at consumer level is colour (Varnam & Sutherland, 1995). An attractive, stable colour in meat and meat products has a major influence on the buying decision of the consumer (Feiner, 2006). Colour is measured objectively by colour instruments as well as by sensory panellists. Parsons, VanOverbeke, Goad & Mireles-DeWitt (2011b) used 4.5% sodium-based phosphate, used in commercial brines, as well as 1% NH_4OH, to measure their impact on beef quality traits, including colour during retail display. The NH_4OH solution performed better than the sodium-based phosphate for the first 6 days of retail display. On day 14, the colour of steaks was found to be unacceptable for both the sodium-based phosphate solution and the NH_4OH solution. Lowder, Goad, Lou, Morgan & DeWitt (2011) substituted dehydrated beef protein for the NH_4OH. They reported that the beef steaks injected with the dehydrated beef protein solution had a less pronounced red colour when compared to the sodium-based phosphate injected steaks. This observation was objectively achieved by utilizing instrumental measurements. Sensory evaluation indicated no differences in redness.

Lactates/acetates are known to stabilise colour in enhancement solutions used in pork (Prestat, Jensen, Robbins, Ryan, Ryan, Zhu, McKeith & Brewer, 2002; Jensen, Robbins, Ryan, Homco-Ryan, McKeith & Brewer, 2003; Livingston, Brewer, Killifer, Bidner & McKeith, 2004). Knock *et al*. (2006) reported an improved visual appearance of beef rib steaks when both potassium lactate or sodium acetate were used in the enhancement solution. These salts also decrease surface sheen. They concluded that potassium or sodium lactates in enhancement solutions would make enhanced beef steaks more appealing to retailers and consumers. They will not only last longer in retail display fridges, but also have a more attractive fresh beef appearance. Mancini, Hunt, Hachmeister, Seyfert, Kropf, Johnson, Cusick & Morrow (2005) used potassium lactate and rosemary. They concluded that, regardless of the mechanism by which this enhancement solution function, beef loins, enhanced with potassium lactate, produced more stable and darker red coloured steaks than rosemary-enhanced steaks. These observations were made throughout a 7-day display period in modified atmosphere packages.

High levels of NaCl (0.6%) in brine solutions have detrimental effects on colour stability, but it reduces shininess. Sodium tri-polyphosphate may also contribute to a darker appearance (Knock *et al*., 2006). Removal of phosphate from the brine solution, on the contrary, resulted in lower sheens (Holmer, McFarlane, McKeith & Killerfer, 2011). Knock *et al*. (2006) hypothesised that ingredients which increase WHC and make steaks appear darker may decrease shininess.

Sensory attributes, in general, may be affected by different factors of brine-injection. These factors may include muscle cut, brine-injection level, amount and type of ingredients used, storage time and the level of brine injected into the meat product. These factors have to be taken into account when evaluating the effect of brine-injection on sensory attributes of meat products with regard to consumer acceptability.

CONSUMER ACCEPTANCE OF BRINE-INJECTED MEAT

Consumer surveys in the US reported that brine-injected meat was deemed as acceptable. Most of these studies confirmed that injecting beef with enhancement solutions have the potential of enhancing beef's sensory attributes. Behrends, Goodson, Koohmaraie, Shackelford, Wheeler, Morgan, Reagan, Gwartney, Wise & Savell (2005) found that marinating did however not improve customer satisfaction of the round steaks. This could be explained by the type of marinade used. Flavour, compared to tenderness, was mostly correlated to 'liked overall'.

Miller, Huffman, Gilbert, Hamman & Ramsey (1995) measured consumer perceptions on calcium-injected beef and control steaks on package labelling acceptance. Consumers surveyed had a favourable response to the beef steaks injected with $CaC1_2$. They described the $CaCl_2$ tenderized steaks to be juicier, more tender and flavourful as well as more palatable than the control steaks. About 50% of the consumers viewed tenderness as the most important attribute, while 40% viewed flavour as most important. The $CaCl_2$-treated steaks, based on package labelling, were visually preferred 71% of the time over the control steaks by consumers.

SHELF-LIFE / EFFECTS OF PACKAGING ATMOSPHERES ON ENHANCED RED MEAT

Case-ready beef has a shelf-life of 2–5 weeks after enhancement, compared to a 5-12 day shelf-life of conventional shrink wrapped fresh packaging (Baczwaski & Mandigo, 2003). Shelf-life extension may be accomplished by the using modified atmospheres in packaging. These modified atmospheres could contain a combination of carbon dioxide, nitrogen and oxygen gases. Marinated or enhanced products may also be vacuum packaged to extend the shelf-life of the refrigerated product.

Calkins & Buford (2005) studied the effects of commercial case-ready packaging systems on shelf-life, colour stability and sensory characteristics of enhanced beef. They found that vacuum-packaging and packaging at high oxygen levels limited detrimental effects on colour and off-flavours. This was found when meat was kept in dark storage for 8 days, compared to a 15 day storage period. Retailers who seek to merchandise enhanced beef products are therefore advised, based on this study, to minimize the time in the marketing chain.

INJECTION LEVELS

It has been shown in the US that beef is usually pumped between 8% and 12% of its original weight (Baczwaski & Mandigo, 2003; Brooks, 2007). Different researchers have used different injection levels in their investigations. It has been stated that if the pump level exceeds 12%, increased package and retail purge may be a concern (Miller, 2010). The level of injection is the same as the yield i.e., meat injected to 10% results in a 110% yield. If meat is over-pumped, an acceptable level of non-meat ingredients may be exceeded (Feiner, 2006). Boles & Shand (2001) injected 10%, 25% and 50%, respectively into different beef meat cuts. Injection level significantly affected the processing characteristics and tenderness of cooked roast beef. Cooking yields increased substantially with brine-injection. Injection at the 25% level resulted in very tender roasts with the highest yields. The 50% injection level was not successfully achieved.

BRINE-INJECTED CURED RED MEAT PRODUCTS

Brine-injected cured products include: beef bacon, corned beef, pastrami and tongue. These products are cured and/or smoked. The main functions of modern commercial meat curing and/or smoking processes are: food safety, refrigerated shelf-life extension, flavour development and colour development (Romans *et al*., 2001). Ingredients generally used in cured meat products include: salt, sugar and other sweeteners, nitrate and nitrite, sodium ascorbate and erythorbate, alkaline phosphates, spices and flavourings as well as water (Townsend & Olson, 1987; Varnam & Surtherland, 1995; Romans *et al*., 2001). A number of other compounds are sometimes also included in curing mixtures. They include: various spices, baking soda, sodium erythorbate, hydrolyzed vegetable proteins, carrageenan and non-meat proteins, etc. Table 1 summarises the basic ingredients used in cured meat and their functions.

Depending on country-specific regulations, there are regulations governing the level of ingredients in cured meat products. In South Africa, the regulations governing emulsifiers, stabilizers, thickeners as well as the quantities thereof in foodstuffs (No. R.2527 of 13 November 1987, as amended) are promulgated under the Foodstuffs, Cosmetics and

Disinfectants Act 1972 (Act No. 54 of 1972; Department of Health, 1972). It prescribes that the following non-meat ingredients may be added in processed and manufactured meat products, including cured ham and pork shoulder: agar, alginates, carrageenan, alginic acid and its ammonium, calcium, potassium and sodium salts, propylene glycol alginate, sodium carboxymethycellulose, carob bean gum, guar gum, chemically modified starches, gelatin and xanthan gum.

Table 1: Cured meat product ingredients and their functions

Ingredient	Function
Water	Serves as Carrier Molecule Increases Product Yield
Salt	Adds Flavour Acts as a Preservative
Sodium/Potassium Nitrate or Nitrite	Curing – Aids in Colour Development)
Sodium Ascorbate/Erythorbate	Accelerates the Curing process
Sugar	Sweetens/(er)
Phosphates	Improve Water Retention
Flavour Enhancers and Spices	Gives products a Flavour Profile Acts as Surface Coatings

Beef Bacon

Bacon is traditionally defined as pork belly, cured with salt, sugar and sodium nitrite, then heat treated, smoked, chilled, sliced and packaged (Mandigo, 2010). In some countries, such as England, bacon refers only to pork. In other parts of the world, the term bacon is used more generally for any meat (Feiner, 2006). In the US, for example, bacon can be made from other species of livestock (e.g. beef) and poultry (e.g. turkey) (USDA–FSIS, 2011c). Beef bacon is a cured and smoked beef product, sliced to resemble regular bacon (USDA–FSIS, 2011c). Most commonly, cured beef cuts are: briskets, strips of round, chuck and plates which can be cured as beef bacon (Ray, 2007).

The processing technology applied to bacon is the same for different species (Romans *et al*. 2001; Mandigo, 2010). Beef bacon is prepared from various beef cuts (USDA–FSIS, 2011d), but it is commonly produced using deboned beef brisket (Feiner, 2006). Beef bacon, compared to pork bacon, has a higher lean content, minor flavouring, a slightly coarser lean texture and increased chewiness (Romans *et al*. 2001). Beef bacon is injected to 20–35% with brine. Following injection, the meat is soaked for 12-48 hours in cover-brine containing at least 3% salt as well as 300 ppm nitrite per litre of brine. Sometimes the injected meat is processed immediately after injection. Subsequent steps will include: hanging the injected brisket, drying at 60–70ºC and smoking at 65–75ºC. Finally, it is steam cooked at 75–80ºC until an internal temperature of 70ºC is reached (Feiner 2006).

Corned beef

Corned beef is generally made from less tender cuts of beef. These cuts include: brisket, rump, round and chuck muscles that has been cured. Corning is a form of curing (Townsend & Olson, 1987; Romans *et al*. 2001; USDA-FSIS, 2011d). Spices and herbs or peppers are commonly added to corned beef. Corned beef can be purchased either cooked or uncooked (Townsend & Olson, 1987; Romans *et al*. 2001).

Pastrami

Pastrami is cured beef, covered with pepper and spices. It is usually cooked and lightly smoked (Townsend & Olson, 1987). Pastrami is usually made from brisket (Satter, 2007). Enzymes, such as papain are included in the brine-injection to tenderise the meat, since brisket is tough (Feiner, 2006). In Australia, pastrami is made from the eye of the silverside. In the US, it is also commonly made from silverside and rarely from beef brisket. In Australia, brine-injection level ranges between 25% and 35%, according to Feiner (2006). In US these levels range between 30 and 40%. Basic ingredients may be used in both countries. Carrageenan and soy are not normally used to increase yield. Products with spices are dried to 60–70ºC, occasionally smoked for a short time to 65-75ºC, then cooked with steam to 75–80ºC, until a core temperature of 70ºC is reached. The final cooking yield for both countries is 110% (Feiner, 2006).

Tongue

Tongue is a cured red meat product. It can be made from ox, lamb and sheep. Those from sheep and pigs are canned as luncheon tongues. It is retailed as a cooked meat. Composition of brine varies according to individual preferences. Nitrate may be omitted but some manufacturers include potassium nitrate. Large tongues are usually artery pumped. Multi-needle injection is widely used for smaller tongues. Yield may however be lower with multi-needle injection. This lower yield can be increased by the addition of polyphosphates to the brine (Varnam & Sutherland, 1995; Oliphant, 1997).

Curing for tongue is carried out in two stages, followed by soaking it in a similar concentration of brine. This brine-soaking process may take 2–7 days. There is normally no maturation period. After curing, tongues are simmered immediately for 1–2 hours, just below 100ºC. Skinning, rooting and trimming follows. The tongue is then packed into cans, usually with the addition of a little gelatine and heat processed afterwards. (Varnam & Sutherland, 1995; Oliphant, 1997).

LEGAL REGULATIONS FOR ADDED WATER AND BRINE-INJECTED RED MEAT AND ITS PRODUCTS

In South Africa, Regulation 28, of the South African regulations, relating to the labelling and advertizing of foodstuffs, (No. 146 of 1 March 2010), under the Foodstuffs, Cosmetics and Disinfectants Act, 1972 (Act 54 of 1972), governs the ingredients which may be added to meat products. It stipulates that water, which is added as an ingredient of a foodstuff during the manufacturing process and exceeds 5% of the finished product, should be declared in the list of ingredients. When water forms part of an ingredient, such as brine, syrup or broth and used in a compound foodstuff, it should be declared as such. Subject to Regulation 18, water that is added as an ingredient of a foodstuff should be declared in the list of ingredients of such foodstuff, unless:

(a) It is used in the manufacturing of the foodstuff, solely for the purpose of wetting a dry additive or ingredient

(b) It is part of brine or syrup, and declared as “brine” or “syrup” in the list of ingredients

(c) The water, which is added, does not exceed 5% of the finished product

The USDA–FSIS (2011a) regulations and policies, in relation to retained water, states that if the carcasses or parts thereof have absorbed water during processing, the amount of water by percentage, along with the terms "retained water" or "absorbed water," (e.g., "up to X% retained water," or "may contain up to X% retained water" or "with X% absorbed water") has to be stated on the label. Beef carcasses and their parts cooled with water during post-evisceration processing must be appropriately labelled with the % retained water statement.

The Foodstuffs, Cosmetics and Disinfectants Act 1972 (Act 54 of 1972), No. R.146 (Department of Health, 2010) also has stipulations regarding labelling of manufactured, processed and fresh processed meat products and mechanically recovered meat. It requires that manufactured meat products have to specify all the protein sources, in descending order of prevalence, in the list of ingredients. This act specifies that, where labelling places special emphasis on the presence of one or more valuable or characterising ingredient(s), or where the description has the same effect, the ingoing percentage of this ingredient, at the time of manufacture, should be declared. It should be in close proximity to the words, illustrations or graphics emphasising a particular ingredient, or directly after the name or description of the foodstuff, or after each characterising, emphasised ingredient listed in the list of ingredients. Regulation 26 (2) of the regulations relating to labelling and advertising of foodstuffs (No. R146 of 1 March 2010), under the Foodstuffs, Cosmetics and Disinfectants Act 1972 (Act 54 of 1972), requires raw processed meat products to indicate the quantitative ingredient declaration (QUID) as a percentage for the meat and water content on the main pane. It has to be in bold letters and at least 3 mm in height.

The FSIS issued policy memoranda for the following to provide guidance for the labelling of enhanced red meat and its products, where solutions are added, or where water- or mist-glazing is utilized. Memos are available on the FSIS website at: http://www.fsis.usda.gov/ OPPDE/larc/Policies/Policy_Memos_082005.pdf. The main memos are summarized in Table 2.

The USDA-FSIS requires enhanced and value-added meats to label the presence and amount of the solution as part of the product name, for example, beef steak marinated with 6% of a flavour solution. The ingredients of the flavour solution must also be prominently identified on the label. This information must be on the principal display panel or the

Table 2: Summary of the FSIS Policy Memos

Policy Memo no.	Subject
066C	Uncooked Red Meat Products containing Added Solutions
084A	Cooked Red Meat Products containing Added Substances
102	Labelling Of Products containing a Component consisting of a Meat with Added Solutions or other Non-meat Ingredients
108B	Water-Misted and Ice-Glazed Meat and Poultry Products
109	Labelling Prominence Guidelines for Cured, Cooked Products withAdded Substances that do not return to Green Weight

information panel. The labelling term "marinated" can only be used with specific amounts of solutions. Marinated meats must contain no more than 10% solution. The qualifying statement must include the percentage of solution contained in the product, e.g., "Marinated with up to 8% of a solution of water, salt, and sugar." Whenever an uncooked, cured red meat product is injected, massaged, tumbled, etc. with a flavouring or seasoning solution, the product name must be qualified with a statement. It should indicate that the addition of a solution has taken place, e.g., "containing 6% of a solution", "injected with up to 12% of a flavouring solution." Addition of enzymatic solutions to meat products is limited to 3% of the raw meat product.

When meat is water-misted or ice-glazed, the net weight of the product may not include the weight of the water or the ice. An acknowledgment to this effect must be indicated on the label application form. A prominent and conspicuous statement must appear on the principal display panel, adjacent to the product name. It should describe that the product is protected with a water-mist or ice-glaze (e.g., "product protected with ice glaze").

The cured, cooked products are covered by sections 319.100 (for corned beef), 319.101 (for corned beef brisket) and 319.102 (for corned beef round and other corned beef cuts).These products' weights, after cooking, exceed the weight of the fresh uncured article. It should bear the product name and qualifying statements on the principal display panel.

In accordance to the abovementioned, the following guidelines should be adhered to:

(a) The product name and the qualifying statements must be prominent and conspicuous.

(b) The label will bear the product name, on the principal display panel. It should be in lettering not less than one-third the size of the largest letter, in terms commonly associated with the product name. These terms could include: cooked, boneless, chopped, pressed, smoked or words which could be a part of the product name, e.g. steak, butt- or shank portion.

(c) The name of the product will be judged prominent if the lettering is of the same style and colour, and on the same colour background as that which is used for the terms commonly associated with the product name or words which could be a part of the product name. If other styles, colours, and/or backgrounds are used, the prominence must be judged equal to those terms and words which could be associated with or part of the product name.

(d) The product name must be distinct and separate from other label information. This name should thus not be part of, or embedded in, qualifying phrases or descriptions that include a list of added solution ingredients. Acceptable terminology include: "corned beef and water product and X % of a solution."

  - Policy Memo 087A, FSIS Directive 7110.2 and Policy Memo 057A outlines that the label for products, covered hereby, must bear qualifying statements which conform to established policies regarding:
    - The size of the lettering in these statements, in relation to product’s name
    - Labels of the applicable products, covered by these memos that must be complied with within 6 months of the date of issuance.

The USDA (2011b) Code of Federal Register specifies the following:

- Firstly it concerns the following products: *corned beef* (9 CFR 319.100), *other corned beef cuts* (CFR 319.102) and *cured beef tongue* (9 CFR 319.103). The application of a curing solution to beef cuts, other than briskets, which are intended for bulk corned beef production, shall not result in an increase of more than 10% in the weight of the finished cured product, over the weight of the fresh uncured meat.

- *Corned beef brisket* (9 CFR 319.101): The application of a curing solution to the beef brisket shall not result in an increase of more than 20% in the weight of the finished cured product over the weight of the fresh uncured brisket. If the product is cooked, the weight of the finished product shall not exceed the weight of the fresh, uncured brisket.

In the EU, the provisions of the Food Labelling Regulations (FLR) 1996 (as amended) and the 2003 Meat Products regulations (MPR) (as amended) are explained in respect of statutory ‘added ingredients’ labelling of meat products. The labelling of meat and poultry products with added water and other ingredients, is controlled by the FLR (1996) (as amended), and the MPR (2003) (as amended). Regulation 8 of the FLR requires food to be labelled with a name which indicates its true nature and which enables it to be distinguished from products with which it could be confused. Regulation 5 of the MPR and 16 of the FLR require that, for a product that resembles a cut, joint, slice, portion or carcass of meat or of cured meat, added water must be mentioned in the name of the food. This regulation applies to added water, where it makes up more than 5% for cooked and uncooked meat or more than 10% of cooked cured meat. Any other ingredient of another (different) animal species added to the meat must also be mentioned. Uncooked cured meats are allowed to contain up to 10% added water, without mentioning the added water in the name of the food on the product label.

In addition, the meat content has to be declared, either in the ingredients list, or as part of, or next to the name of the food, which indirectly indicates the amount of added water. Red meats, e.g. pork-, lamb- and beef products are also covered by this regulation. These products may be in the form of chops, steaks (e.g. fillet or sirloin), joints, loin joints, medallions, loin steaks, shoulder joints, leg joints, rib-roasts, stir-fry strips, ham, bacon and other cured meats (e.g. pastrami, salt beef), etc. Products from other ‘exotic’ species like game (e.g. venison), pheasant as well as wild duck (in the form of joints), etc. also fall under the jurisdiction of this regulation (Food Standards Agency, 2010).

CONCLUSIONS

Processing methods, such as brine-injection, can be used to create beef products that will satisfy both the modern consumer's and the retailer's demands. Brine-injection, for instance, will improve not only the palatability of beef, but also extend shelf-life. It appears to have potential benefits for the red meat industry, provided that it is executed correctly and in a responsible way. Studies have proven that brine-injection could be of great importance to expedite the beef industry's efforts to improve product quality and consistency. This process of enhancement has to be regulated very strictly. This will prevent consumers from having health problems (increasing the risk of stroke with high sodium levels) and also discourage factories and retailers from taking advantage of the increased weight to increase their profits to the detriment of the consumer.

FUTURE RESEARCH

It is important that further research be done on sheep and lamb, as most research in this field, to date, has been focused on beef.

There is also a need to optimise brine-injection levels, as currently used in the meat industry, to increase quality. Currently, there is no legislation in South Africa which regulates brine-injection levels and added water in red meat during processing. It is therefore necessary to develop methods to enable analysts to make an accurate estimation of the amount of brine injected into the meat. Techniques that is currently utilized in the red meat industry, also needs to be re-evaluated. It would serve the industry well to invest in techniques and/or appliances that could lead to a faster and therefore a more efficient way to assess the quality of the brine-injected products while still in the production line.

More research also has to be done to investigate the consumer acceptance level of brine-injected red meat in South Africa. Employing consumer opinions to assess the quality, consistency and value of brine-injected beef or beef products, sold at retail stores, could well be established through benchmarking.

Lots of research has been done with regard to the sensory analysis of brine-injected meat. It would be fair towards the consumers to know the nutritive value of brine-injected red meat. There is also a need to investigate the proximate composition of brine-injected red meat, as compared to non-injected meat.

Needle-injection of brine may cause an increase in the number of spoilage organisms and the incidence of food-borne pathogens in meat. Studies on the shelf life and pathogen status of brine injected red meat must therefore be performed urgently.

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